Technical Support for Bus Service Planning

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1 Introduction

The purpose of this paper is to stimulate interest in the issue of organising data to assist in the planning of bus routes. In particular, we are interested in how to expand the range of bus routes efficiently, how to make existing route patterns more effective and how bus routes inter-relate with rail-based public transport. This paper presents a simple spreadsheet model for route planning and demonstrates how it can be used to assist in bus route planning decisions.

2 Background

A widely-known example of an analytical approach is embodied in the VIPS modelling system, developed by Volvo Bus in the 1980s and now managed by German company PTV AG (PTV Scandinavia 2006). VIPS uses detailed origin-destination surveys of public transport users to construct passenger matrices which are assigned to the public transport network in a very detailed procedure. Passengers' knowledge of the timetable, links to rail services and interaction with car travel can be taken into account.

A similar approach (IMPACTS) was developed by Travers Morgan and applied in a number of Australian and New Zealand cities (Wallis et al 1989, Crouch et al 1992). This again used detailed origin-destination surveys of public transport users in conjunction with a public transport network and assignment procedure. Demand elasticities to service levels enabled demand changes to be forecast.

In Auckland, the Auckland Passenger Transport Model (APT) is similarly based on public transport OD surveys, a public transport network and assignment procedure and uses elasticity-based forecasting techniques.

Other more general transport modelling software packages, such as VISUM, Cube, EMME and TransCAD provide public transport modelling functionality, though these systems are typically designed for more strategic multi-modal applications. They are frequently used for public transport planning, being in our view most suitable for network strategy appraisal and in some cases for rail project appraisal. Generally it is our understanding, and expectation, that would be insufficiently accurate for bus route planning.

Thus, while analytical software has been used for public transport planning in Australia and New Zealand, our experience is that analytical systems are not widely used for bus patronage forecasting, route and service planning. There are good reasons for this: for example, short distance trips are often difficult to model due to the detail required, and institutional practices (related to service contracting) may govern route planning. Despite these considerations, it is still useful to ask the question of whether suitable analytical procedures could be readily set up as an aid to bus planners.

In considering methods, we wished to focus on analytical approaches to bus service planning so as to better cater for expected levels of demand and generated travel. We also expect that over the last 20 years software packages and knowledge of transport behaviour have developed so rapidly that much could be achieved using readily available software packages without the need to purchase another tool.

3 Current procedures

Procedures currently used in bus route planning tend to focus on the practical aspects of the intended route, such as service coverage, proximity to residential areas and major trip generators, connections to rail services, and the directness of the route (see for example Public Transport Authority of Western Australia 2003). Planners tend not to optimise routes according to patronage by a formal modelling process, instead relying on professional judgement and local knowledge.

Where sufficient data are available to carry out modelling, there are a number of sketch-planning patronage forecasting methods available for planners. Some of the more common methods include benchmarking and elasticities.

Benchmarking uses existing demand performance measures as a 'rule of thumb' to make forecasts. It considers the characteristics of an existing service or similar services, preferably in the same geographical area as a proposed service, using inputs such as current patronage, bus kilometres and frequencies to give an approximate patronage forecast.

Elasticity forecasting uses the ratio of the relative change in demand to the relative change in any demand-influencing factor (such as fares, bus travel times, fuel costs and parking charges). Elasticities provide a simple method for preparing first-cut, aggregate response estimates for a wide range of impacts, providing there is an existing market.

4 Illustration of an analytical approach

The model described in this paper is a pilot, designed to illustrate an approach. It is designed to use easily-obtainable data. The implementation is via an Excel spreadsheet, but a real implementation would probably use packages like EMME2 or Cube.

4.1 The geographical structure

We have a small town/city divided into 196 zones (Figure 1). For the pilot this was a convenient size of problem – for any major city a larger zone system would be used. In this we have identified the land use and key public transport generators: outer and inner urban areas, major retail centres, major employment centres and secondary schools.

4.2 Public transport trip generation

To these different types of area we have attributed broadly typical population characteristics of Australian/NZ cities (Table 1) – related to their public transport trip generation characteristics (generation of public transport trips by residents). These data were taken from the census.

We have also attributed attraction characteristics (Table 2), related to the amount of employment, the size of the retail areas and the schools.

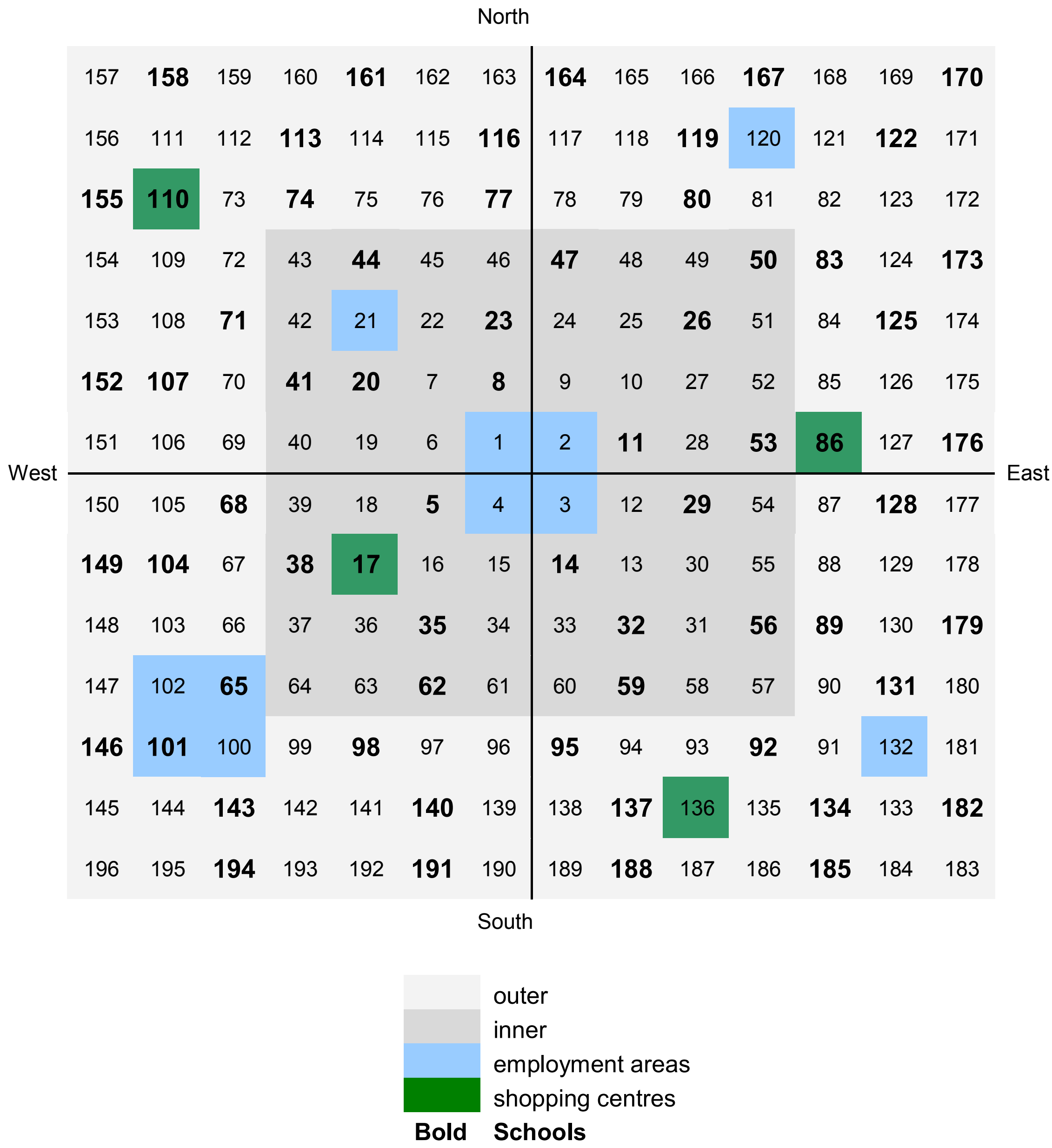


Figure 1 City zoning and layout

Table 1 Hypothetical population and household characteristics

<table>
<tr><th rowspan="3"></th><th colspan="9">Area</th></tr>
<tr><th rowspan="2">CBD</th><th colspan="4">Inner</th><th colspan="4">Outer</th></tr>
<tr><th>NE</th><th>SE</th><th>SW</th><th>NW</th><th>NE</th><th>SE</th><th>SW</th><th>NW</th></tr>
<tr><td colspan="10">Population Characteristics</td></tr>
<tr><td>Density (people/km²)</td><td>2000</td><td colspan="4">600</td><td>400</td><td colspan="2">300</td><td>400</td></tr>
<tr><td>Age 0-10</td><td>15%</td><td colspan="4">15%</td><td colspan="4">15%</td></tr>
<tr><td>Age 10-19</td><td>9%</td><td colspan="4">15%</td><td colspan="4">18%</td></tr>
<tr><td>Age 20-60</td><td>48%</td><td colspan="4">59%</td><td colspan="4">47%</td></tr>
<tr><td>Age 60+</td><td>28%</td><td colspan="4">11%</td><td colspan="4">20%</td></tr>
<tr><td colspan="10">Household Characteristics</td></tr>
<tr><td>Employees / household</td><td>0.85</td><td>0.57</td><td colspan="2">0.73</td><td>0.57</td><td colspan="4">0.73</td></tr>
<tr><td>Household Income p.a.</td><td>$46000</td><td>$67000</td><td colspan="2">$32000</td><td>$67000</td><td colspan="2">$32000</td><td colspan="2">$25000</td></tr>
<tr><td>Cars / Household</td><td>1.5</td><td>2.2</td><td colspan="2">1.2</td><td>2.2</td><td colspan="2">1.2</td><td colspan="2">1.3</td></tr>
</table>

Table 2 Attraction characteristics

Characteristics	Statistics
Zone area (km^2) – assumes equal zone sizes	16.0
City Population	203,191
Schoolchildren	30,479
Total Employment	83,064
Employment in CBD	33,226
Employment in other employment centres	24,919
Total retail employment	12,460
Retail employment in CBD	3,115
Retail employment in other shopping centres	3,115

The trip generation rates that we have assumed are given in Table 3. Similarly trip attraction rates are given in Table 4. Trip rates of this type have been determined from household travel surveys such as the Victorian Activity and Travel Survey (McGinley 2001). School, work and shopping trips have been used in this example, but additional trip purposes could also be included.

While it might seem that household travel surveys are the most appropriate source for these trip rates, in many cities, because of the low public transport mode shares, the samples of public transport trips obtained in such surveys are insufficient for examining public transport trip rates in detail. In this situation, public transport intercept surveys - which are capable of providing far higher samples of public transport users - would be needed.

Table 3 Daily public transport trip generation rates

Purpose	Age		
	10-19	20-60	60+
School	0.60	0.00	0.00
Work	0.00	0.20	0.00
Shop	0.10	0.05	0.10
Trip rates reduce with increasing car ownership			
Trip rates reduce with increasing income			

Table 4 Daily public transport trip attraction rates

Purpose	Total Employment	Retail Employment	Schools
School	0	0	0.427
Work	0.179	0	0
Shop	0	0.69	0

These trip rates may be viewed as "potential average" values in the sense that without public transport services they would not be realised. With exceptionally good services, higher than average trip rates could presumably be generated.

4.3 Public transport routes and services

Public transport routes are described by the sequence of zones through which they pass.

In this simple model the diameter of each zone is identical (5.6 km) and this is assumed to be the distance the bus or train travels within the zone, unless it is a residential area, where a bus route which is designed to circulate through the residential area may be allocated a larger distance within the zone. From these figures the overall length of the route is determined. In real applications of the model, the zones would probably differ in size and bus travel distances would differ from zone to zone.

Different operating speeds are assumed for bus and rail, enabling journey times for each route to be estimated. Service headways are allocated to each route and combined to give a route generalised time. The inclusion of a distance-related fare function could also allow a generalised cost of travel for passengers to be estimated.

4.3.1 Allocation of Public Transport Passengers to Individual Routes

The model then seeks to allocate the generated public transport trips to routes which connect the generation zones with the available, required attractions.

Patronage is allocated separately for each of the three purposes: work, school and shop. Taking work trips as an example, the process is in two parts.

In the first place, generated public transport work trips from a residential zone are allocated to all the workplace zones accessible by public transport. The allocation process is sensitive to (i) the number of workplaces in each attraction zone and (ii) the accessibility of the workplace zone from the residential zone using public transport. In other words, proportionally more work trips are allocated to larger, nearer zones.

The measure of accessibility is:

$$acc_{ij} = A_j \cdot \exp(\beta c_{ij})$$

where:

acc_{ij} is the accessibility of generation zone *i* to attraction zone *j*
A_j is the number of 'attractions' in zone *j* (eg. retail employment)
c_{ij} is the generalised costs of travel by public transport between *i* and *j*.

The public transport trip generations are allocated using the formula:

$$PT_{ij} = F_i \cdot G_i \cdot \left(\frac{acc_{ij}}{\sum_j acc_{ij}} \right)$$

where:

F_i is an accessibility adjustment factor (see below)
G_i is the generation for zone *i*

The public transport trip generation rates estimated from current travel patterns represent current average values. For zones with very poor public transport connections, the level of public transport use would inevitably be lower than this. Conversely zones with higher public transport accessibility are likely to have higher than average public transport trip generation rates. These assumptions are accounted for with the F_i accessibility adjustment factor.

To calculate the factor, the workplace accessibility by public transport to workplaces of each zone is compared with a typical average accessibility for the city as a whole and, using an elasticity, the overall trip rate is increased (or decreased) if its accessibility is higher (or lower) than this average.

The trip generations are multiplied by the factor:

$$F_i = 1 + \alpha \left(\frac{\sum_j acc_{ij}}{acc_{datum}} - 1 \right)$$

where:

acc_{datum} is the accessibility datum (ie. a typical average accessibility)
and α defines the sensitivity of trip rates to accessibility (ie. the elasticity)

In this way, new and improved public transport services are forecast to achieve two changes. There is (i) a re-distribution of work trips towards more accessible workplaces and (ii) also an increase in the overall number of work trips by public transport resulting from the overall increase in accessibility.

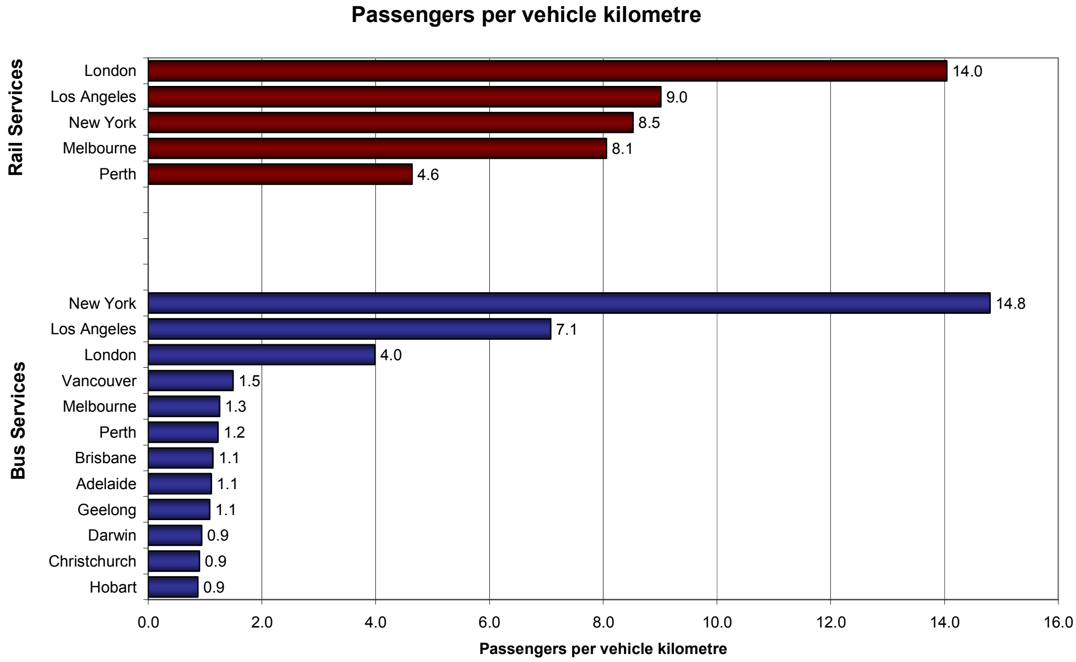
Given information on existing public transport travel patterns, it seems likely that these various allocation and accessibility functions could be either estimated or validated. This said, in most contexts adequately detailed information would only be obtained from a public transport intercept survey. Given such data, the option of basing the approach on the observed travel patterns and applying these functions incrementally would also be attractive.

4.3.2 Outputs

Given an existing set of public transport routes and services, the model allows new and improved routes and services to be tested with the outputs including:

- for an operating day, the total vehicle-kilometres for each route and the complete network (by mode);
- the number of passengers for each route and the complete network (by mode);
- the ratio of these two factors providing an measure of the efficiency of the new route and the overall network (by mode).

Typical ratios of passengers per vehicle kilometer (PVK) are shown in Figure 2. Generally, a desirable PVK for rail services falls between 5 and 10 and for bus services between 2 and 4.



Sources: various, but including Institute of Transport Studies (Monash University) quoting several Australian sources and the London Travel Report 2005.

Figure 2 Typical PVK estimates for international cities

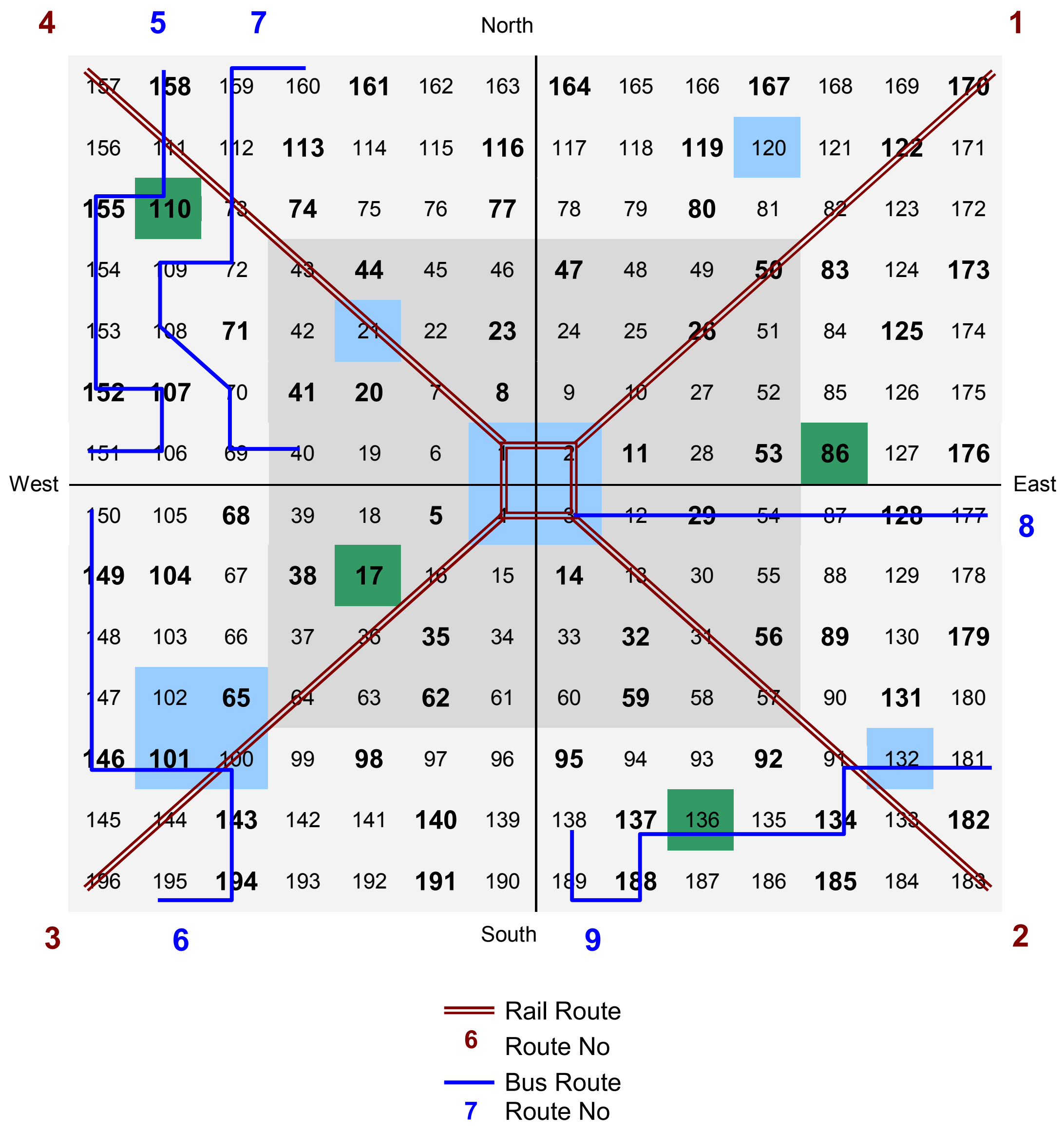


Figure 3 Bus and rail network layout

4.4 Illustrative results

Figure 3 sets out the test network from which illustrative results will be given. Initially, the network has been populated with standard, non-optimised headways of 30 minutes for rail services and 15 minutes for bus services. This produces 114,500 public transport trips, with the characteristics summarised in Table 5.

Table 5: Network performance statistics (non-optimised)

	Rail				Bus					Total
Route	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	
Headway	30	30	30	30	15	15	15	15	15	
Speed	50	50	50	50	20	20	20	20	20	
Route distance	52	52	51	52	80	80	83	80	72	601
Vehicle km ('000)	5.3	5.3	5.3	5.3	16.5	16.5	17.2	16.5	14.9	103
Passenger trips ('000)	23.1	16.8	22.4	15.9	8.5	11.0	2.4	8.5	5.9	114.5
PVK	4.3	3.1	4.2	3.0	0.5	0.7	0.1	0.5	0.4	1.1

Individually, the PVK ratios range between 3 and 4.3 for rail services and 0.1 and 0.7 for the bus services. In order to optimise the network, individual characteristics including the location of the public transport routes and headways of individual routes can be altered.

4.4.1 Locations of routes

The location of bus routes in relation to attractors such as workplaces or schools has a large effect on the patronage of an individual service. In order to maximise the attraction of a route, it should be carefully designed to be of the most use to the greatest number of passengers, and should travel to areas of high activity and attraction.

To illustrate this, Route 7 (see Figure 3), which travels through the outer areas of the model and passes through no areas of employment, shopping centres or schools has an extremely low PVK of 0.1 and attracts 2,300 passengers. Route 5, which has a similar route length and passes through five zones containing schools and a shopping centre has a non-optimised PVK of 0.5 and attracts 8,500 passengers.

4.4.2 Route mode choice

Route 1, currently a train-based route, has a PVK of 4.3 and attracts 23,100 trips. If this route is transformed into a bus route (essentially by reducing the travel speed) while maintaining the same headway, its PVK drops to 0.2 and attracts only 2,600 trips. Rail routes are traditionally much better trip attractors than buses, having higher average travel speeds and generally better reliability, but have much higher capital and operating costs.

4.4.3 Headways

As the headway of a service decreases, the more attractive it becomes (due to reduced average waiting times). However, short headways increase the operating costs associated with a route, so optimisation needs to consider operating cost as well as patronage. In this case, the headway has been selected through a process of iteration to give the highest PVK. In Table 6, the rail headways have been decreased to between 12 and 19 minutes, whereas the bus headways have been increased to between 29 and 93 minutes. The overall PVK of the network has increased from 1.1 to 2.8, with increases and decreases of patronage created on individual lines, with the overall patronage of the network increasing by 80% to 207,000 trips. In a real-life situation, headways of 93 minutes would not be acceptable, and in Table 7, we have used more sensible headways (rounded to the nearest 5 minutes with maximum headway of 60 minutes) retaining most of the benefits of the improved network.

Table 6 Optimised results

	Rail				Bus					Total
	1	2	3	4	5	6	7	8	9	
Headway	12	18	19	19	29	29	93	29	29	
Speed	50	50	50	50	20	20	20	20	20	
Route distance	52	52	51	52	80	80	83	80	72	601
Vehicle km ('000)	13.5	8.8	8.4	8.3	8.5	8.5	2.8	8.5	7.6	75
Passenger trips ('000)	91.7	30.9	38.6	26.2	4.5	5.9	1.3	4.8	3.2	207
PVK	6.8	3.5	4.6	3.1	0.5	0.7	0.5	0.6	0.4	2.8
Change in patronage	+297%	+84%	+72%	+65%	-47%	-47%	-47%	-44%	-46%	+81%

Table 7 Optimised results with "sensible" headways

	Rail				Bus					Total
	1	2	3	4	5	6	7	8	9	
Headway	10	20	20	20	30	30	60	30	30	
Speed	50	50	50	50	20	20	20	20	20	
Route distance	52	52	51	52	80	80	83	80	72	601
Vehicle km ('000)	16.0	8.0	8.0	8.0	8.3	8.3	4.3	8.3	7.4	76
Passenger trips ('000)	107.4	27.9	36.6	25.1	4.4	5.7	1.8	4.6	3.1	217
PVK	6.7	3.5	4.6	3.1	0.5	0.7	0.4	0.6	0.4	2.8
Change in patronage	+365%	+66%	+63%	+58%	-49%	-48%	-27%	-45%	-47%	+89%

5 Summary and conclusion

The pilot bus planning model described in this paper has been specifically designed to test the impacts of new and redesigned routes and services. In principle, it does not rely on existing public transport origin-destination surveys although in practice these would be helpful in verifying its general performance, establishing some of the parameters and generally improving the quality of representation. Indeed this is the lesson of the examples which we quoted at the beginning of the paper. Otherwise, the model can be based on readily available information (household travel surveys, census and other databases) and can operate at the very fine area level appropriate to bus service planning.

While we would not want to assert that this is all planners need for bus service planning, we suggest that organising and presenting information in this way offers the bus service planner a framework for analysing how the existing pattern of services may be improved and for evaluating the potential for new services. Our purpose in developing this pilot approach has been to demonstrate its practicability.

Underlying the concept for the paper is the view that the "horses for courses" adage applies to transport modelling and analysis. Too often, analytical techniques are rejected in transport planning because an available (but inappropriate) model system is applied to a problem, giving inaccurate answers. In other words, while many strategic transport models are not able to address bus planning issues with sufficient precision, there are other methods, such as we have described here, that offer the potential for much greater precision.

References

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